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T 75-15499  
76-10473  
CR-144383  
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AN EVALUATION OF SKYLAB (EREP) REMOTE SENSING TECHNIQUES  
APPLIED TO INVESTIGATIONS OF CRUSTAL STRUCTURE

Contract No. NAS9-14235  
Task/Site No. 222198

N76-31620  
MC 3,520  
10473

Prepared by:

Ira C. Bechtold  
Principal Investigator  
ID 541

SEMIANNUAL REPORT  
1 July - 31 December 1974

Submitted by:

BECHTOLD SATELLITE TECHNOLOGY CORPORATION  
17137 East Gale Avenue  
City of Industry, California 91745

BESTEC Report 101-SA-6/75

(EE76-10473) AN EVALUATION OF SKYLAB (EREP)  
REMOTE SENSING TECHNIQUES APPLIED TO  
INVESTIGATION OF CRUSTAL STRUCTURE  
Semiannual Report, 1 Jul. - 31 Dec. 1974  
(Bechtold Satellite Technology Corp.) 17 p G3/43 00473

Contract Monitor:

David Amsbury, Code TF6  
Earth Observations Division  
NASA - Lyndon B. Johnson Space Center  
Houston, Texas 77058

**MARY COPY**

AUG 25 1975

JOHNSON SPACE CENTER  
HOUSTON, TEXAS

## TECHNICAL REPORT STANDARD TITLE PAGE

|  |  |   |            |                            |
|--|--|---|------------|----------------------------|
| 1. Report No.  | 2. Report Accession No.                              |   |            | 3. Recipient's Catalog No. |
| 4. Title and Subtitle SEMIANNUAL REPORT<br>1 Jul-31 Dec 1974: An Evaluation of Skylab (EREP) Remote Sensing Techniques Applied to Investigation of Crustal Structure |  | 5. Report Date  |            |                            |
| 7. Author(s)<br>Ira C. Bechtold  |  | 6. Performing Organization Code<br>none   |            |                            |
| 9. Performing Organization Name and Address<br>Bechtold Satellite Technology Corp.<br>17137 East Gale Avenue<br>City of Industry, California 91745                   |  | 6. Performing Organization Report No.<br>BESTEC 101-SA-6/75   |            |                            |
| 12. Sponsoring Agency Name and Address<br>NASA - Lyndon B. Johnson Space Center<br>Technical Support Procurement Branch<br>Houston, Texas 77058                      |  | 10. Work Unit No.   |            |                            |
| 15. Supplementary Notes  |  | 11. Contract or Grant No.<br>NAS9-14235   |            |                            |
| 16. Abstract   |  | 13. Type of Report and Period Covered<br>SEMIANNUAL REPORT<br>1 Jul-31 Dec 1974   |            |                            |
| 17. Key words (Selected by Author(s))<br>Resources exploration<br>Skylab imagery<br>Geology<br>Interpretation techniques   |  | 18. Distribution Statement<br>Dr. David Amsbury/TF6<br>Earth Observations Division<br>NASA - LBJ Space Center<br>Houston, Texas 77058 |            |                            |
| 19. Security Classif. (of this report)<br>Unclassified   | 20. Security Classif. (of this page)<br>Unclassified | 21. No. of Pages<br>15  | 22. Price* |                            |

\*For sale by the Clearinghouse for Federal Scientific and Technical Information, Springfield, Virginia 22151.

Technical Report Standard Title Page

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AN EVALUATION OF SKYLAB (EREP) REMOTE SENSING TECHNIQUES  
APPLIED TO INVESTIGATIONS OF CRUSTAL STRUCTURE

I. PROGRAM SUMMARY

Introduction:

The purposes of this study are to analyze, interpret, and evaluate data and imagery from the Skylab (EREP) earth-looking sensors and apply these results to mineral, petroleum, geothermal, and water resources exploration. Additionally, Skylab products are to be compared to other space-orbiting and aerial remote sensing techniques, such as ERTS imagery, X-15, Apollo spacecraft, and high-altitude aircraft photography for an evaluation of usefulness to geological investigations. Interpretations made from remote sensing data are to be confirmed and extended by studies of published geological and geophysical reports and maps, as well as on-site field reconnaissance surveys.

Test Area:

The area chosen for the study is a 70,000 square mile rectangle encompassing parts of Arizona, California, Nevada, and Utah (see Figure 1). Most of the area is a part of the Basin and Range physiographic province and is characterized by elongate, partially-buried fault blocks of variable structure and rock type separated by broad, alluvial-filled basins. Parts of the Colorado Plateaus, a region of relatively unfaulted, flat-lying, Paleozoic sedimentary rocks, and the granitic Sierra Nevada massif are also included in the test area. Thus, investigations of remote sensing data and imagery are being conducted over a variety of geologic environments.

The mineral wealth of the area is exemplified by the large deposits currently being mined, such as the Duval copper porphyry deposit in northwestern Arizona, the iron deposits of southwestern Utah, the Goldfield-Tonopah and Pioche areas in Nevada, and the borax deposits in California. Numerous mining districts, currently inactive, produced millions of dollars in mineral deposits. Many small mines are active in the test area and abandoned shafts, pits, and tunnels signify that the area has been extensively explored for mineral deposits.

Description of Facilities:

Facilities committed to the NASA investigation by BESTEC include an International Imaging Systems (I<sup>2</sup>S) color additive viewer, Model 6040PT. This viewer, designed to accept 70mm film chips,

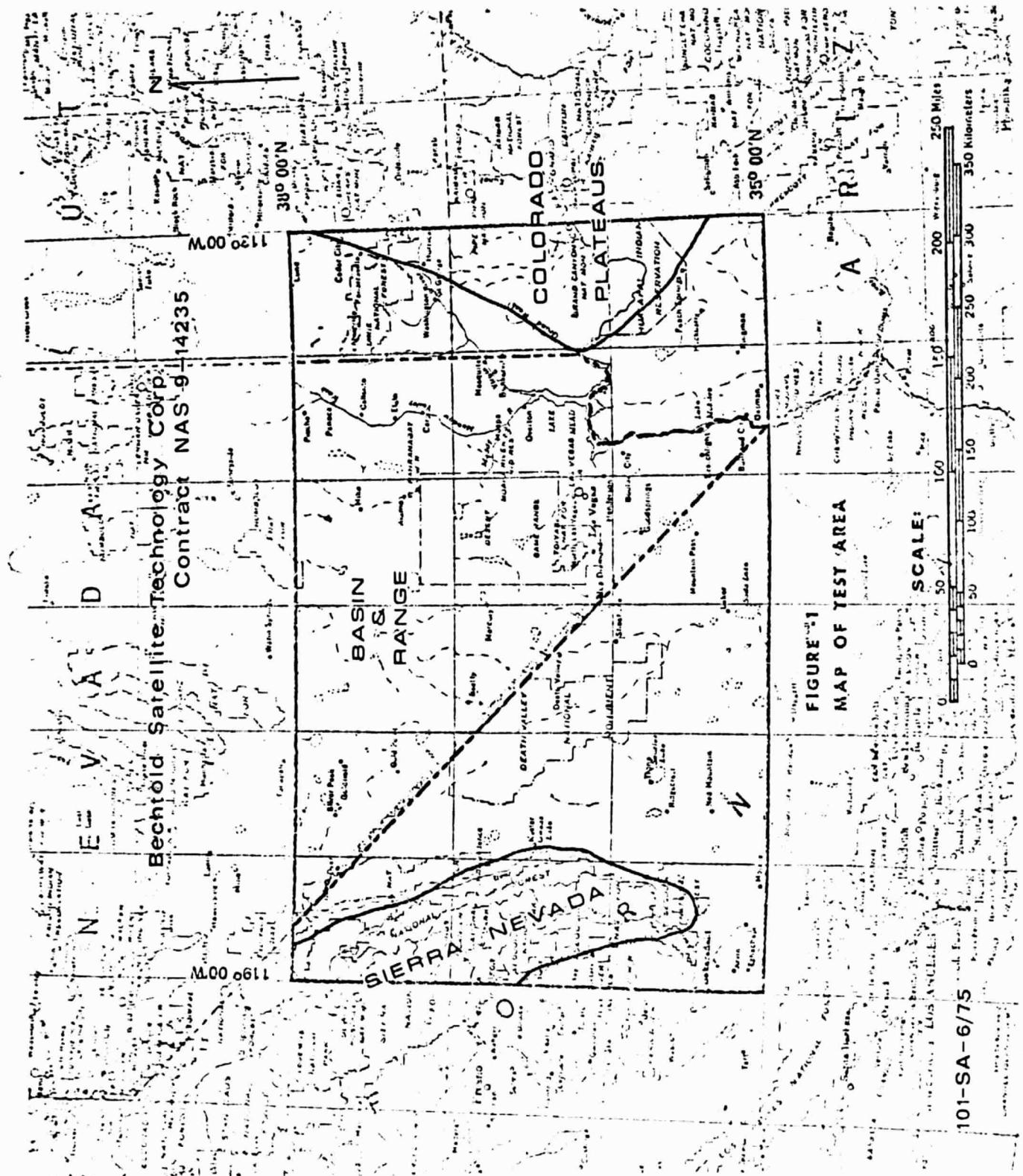


FIGURE 1  
MAP OF TEST AREA

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displays the image on a Polacoat viewing screen suitable for tracing image detail at an enlargement factor of 6.7. It also projects images at magnification up to 20X from the rear of the machine onto a vertical, opaque screen. Any image available in 35mm or 70mm film chips such as ERTS MSS and RBV, Skylab S190A and handheld, U-2, and RB-57 can be analyzed in the I<sup>2</sup>S viewer.

Other standard image viewing instruments such as microfilm readers, light tables, stereoscopes, monoscopes, reducing lenses, and magnifying glasses are also available for the study.

An extensive library of literature and maps (geological, geophysical, topographical) pertaining to the test area has been compiled to complement imagery studies. Much of the material has been transferred from the private collections of Mr. Ira C. Bechtold; other references have been received from federal and state government agencies, universities, and industry.

A reliable and efficient filing, cataloging, and indexing system for imagery has been developed for the investigation. The system contains approximately 400 scenes of ERTS and Skylab imagery supplied by NASA under the Skylab contract, in addition to many hundreds of frames of Skylab, ERTS, Gemini, Apollo, X-15, Nimbus, and U-2 imagery already in BESTEC's or Mr. Bechtold's files. All imagery has been indexed by place names and filed according to NASA identification numbers.

Other equipment supplied by BESTEC for the investigation includes a GMC 4-wheel drive truck, specially equipped for geologic field work, and a portable proton magnetometer that will be available for field use later in the study.

#### Accomplishments:

During the six-month period discussed in this report, major effort proceeded in three main phases:

1. organization
2. inspection
3. investigation

The organizational phase included the establishment of office facilities to execute the Skylab investigation, the development of office procedures, and the familiarization of BESTEC personnel with the requirements of the NASA contract and the specifics of the EREP program. During this phase, a process for handling imagery was designed and initiated. The process involved preliminary evaluation of the quality of NASA supplied imagery and filing of all products (70mm positive and negative films, 5- and 9-inch positives, negatives, and prints) for each scene in one readily-accessible location. Each image was cross-referenced

with place names. The process was much more complex and time-consuming than originally anticipated due to the large volumes of imagery received from NASA. The value of the comprehensive imagery files has been frequently demonstrated in investigations, however.

The inspection phase was essentially an intermediate stage, providing the transition from organization of the investigation to active interpretation of EREP data and field work. During this phase, Skylab imagery was visually inspected on light tables to determine:

1. how completely the test area was imaged by the S190A multispectral photographic and S190B earth terrain cameras by each of the three manned missions;
2. the presence of scratches and fogging in the film;
3. characteristics of each magazine (color, contrast, resolution, scale) and cloud cover of each frame;
4. percent end lap per frame for each 190A and 190B magazine; and
5. relative usefulness of different Skylab products (70mm films, 5- and 9-inch films) and of different film types for geologic investigations.

In addition, the imagery was analyzed to determine if ground sites, predetermined to be of interest to this investigation, were imaged by EREP sensors. A listing of other areas noted in Skylab imagery that displayed unusual or anomalous color, textural, linear, or arcuate features was compiled; all imagery over these areas was analyzed to ascertain if the anomaly was real (related to the cultural or geological environment) or a product of film processing.

S192 screening films were viewed and specific fragments of data were selected by BESTEC investigators and reported to NASA for processing of all channels into 70mm, line-straightened imagery. Selection was based on determination of geologically significant anomalies possibly related to mineral deposits as noted during analyses of 190A and B transparencies.

The third phase of the investigation encompasses detailed imagery studies and interpretation of anomalies. There are three steps in a comprehensive study of an anomaly:

1. analyses of imagery, first using EREP data, then substantiating interpretations with imagery from other spacecraft and aircraft;
2. corroborating results with reference material; and

3. confirming interpretations with on-site field reconnaissance surveys and evaluating their significance to mineral exploration in the area of the anomaly.

Included in the third phase is the preparation of monthly progress reports, special reports, publications, and oral presentations.

During the first six months of this investigation, approximately twelve sites or anomalies were examined in detail using EREP data as the primary tool. Two short field reconnaissances were conducted to check ground geology in areas of interest. Two areas of particular interest were reported in the November monthly report -- Hunter Mountain and Greenwater Valley-Black Mountains, both in California.

Significant Results:

The following significant results have been previously reported:

Studies of S190A imagery support the conclusions of Bechtold and Jahns (1971) that altered rocks can be easily identified in color infrared films.

High resolution S190B photography permits the location of structural features that control geothermal activity more accurately than is possible with other spacecraft data.

Films from all six S190A multispectral photographic camera stations (for any one scene) can be registered and analyzed in a color additive viewer (four films at a time).

S190A and B films are excellent for geologic interpretation at 18X-19X magnification.

A study of 190A and 190B images of the northern Panamint Range, California, reveals a prominent arcuate structure five to six miles in diameter. This structure exhibits topographic, vegetative, and color anomalies having high correlation with mineralized zones, copper deposits in particular. Field reconnaissance confirms this interpretation. (Summary of this study was reported in November monthly report; full length report is in preparation.)

Near the abandoned townsite of Greenwater, Death Valley area, field examination of color anomalies and linears interpreted to be alteration zones and fractures, respectively, has resulted in the conclusion that copper deposits are localized at intersections of the two features. (Summary of this study was reported in November monthly report; full length report is in preparation.)

Anomalous colorations determined to be alteration zones correlate with many mapped mining areas in Nevada and California. Extension of the zones beyond the known areas suggest areas of additional mineralization.

Another significant result not previously reported is a study of Greenwater Valley which indicates that the valley is bounded on the north and east by faults, on the south by a basement high, and on the west by the dip slope of the Black Mountains. Movement of groundwater from the valley is thus restricted, indicating the valley is a potential water reservoir.

## II. DISCUSSION OF IMAGERY

### S190A Multispectral Camera Photography:

Over 70% of the 70,000 square mile test area was photographed at least once by the S190A cameras. Five Skylab tracks traversed the test area, three descending (63,20,6) and two ascending (16, 59). There were 14 different S190A data-gathering EREP passes over those tracks; NASA supplied BESTEC with photography from eight of the 14 passes (42 frames).

As specified in the data requirements section of BESTEC's Skylab contract, NASA supplied only that imagery exhibiting less than 30% cloud cover. On several occasions, however, we requested copies of S190A frames over sites of particular interest even though catalogs and reference maps indicated cloud cover of the frame was greater than 30%. Cloud-covered frames were requested only if no other Skylab data was available over the site of interest. Fortunately, windows in the clouds were located over the sites in some of the requested frames.

A few areas were photographed on more than one EREP pass, which permitted evaluations under different climatic conditions and different sun angles. For example, photography for the Lake Mead region is available from S190A magazines 04 (SL2 - June 1973), 28 (SL3 - September 1973), and 4B (SL4 - February 1974).

S190A photography was received in sleeved 70mm film positives and, just recently, in 9-inch (4X) film positives and negatives (for black and white films only).

The quality of the films is generally excellent regarding fogging, spots, and scratches due to processing. The small scale of the film chips (1:2,850,000) makes geological analysis impossible, but it is adequate for an evaluation of quality, cloud cover, and geographic area covered by the frame as well as an appraisal of the resolution and color contrast. The chips are interpreted

in an I<sup>2</sup>S multispectral viewer which enlarges them 6.67X to a scale approximately 1:425,000.

The projection results in some loss of detail, especially in the Ektachrome films, but this is attributed mostly to the Polacoat screen and optical degradation inherent in the viewer.

70mm chips have been composited (four at a time) with no registration problems. No single configuration of light intensities, color filters, and spectral bands has proven best for investigations of all magazines.

The black and white IR exhibits poor resolution (graininess) and generally detracts from the composited image. Ektachrome chips are perhaps overall the most useful; but the black and white band 5 usually has the best resolution.

Projecting S190A chips through the rear of the I<sup>2</sup>S viewer permits enlargements of 20X from the 70mm size. In this way, S190A can be registered directly onto published maps of conventional scales: 1:250,000 and 1:62,500. The image is still very useful if viewed in a darkened room where incident light cannot detract from the image. Obviously, some resolution and color contrast is lost at enlargements of this magnitude; we interpret the frame at 6.67X before the larger projection.

Photographic enhancement of 190A films has not yet been attempted. It is anticipated that the same procedure used to enhance ERTS will be successful for the black and white 70mm films. Currently we are processing some 190A Ektachromes into prints, enhancing the interneg by varying exposure times.

Stereo-viewing capabilities of S190A have not been fully investigated but appear to be very useful. Magazine 4B over the Lake Mead area and into northwest Arizona has been examined using a stereoscope. Several short linears observed are interpreted to be normal faults. They were not noted during conventional monoscopic analysis.

Several features of the S190A multispectral camera photography are especially useful to geological investigations:

1. availability in several spectral bands
2. capability of false-color compositing in a multispectral viewer
3. resolution (better than ERTS)
4. endlap: stereo viewing capabilities
5. Ektachrome films: more subtle color variations can be detected than is possible with ERTS; many times, the

color contrast is as good as that of the Apollo 6 photography which exhibits excellent color contrast due to a low sun angle.

S190B Earth Terrain Camera Photography:

The very high resolution of 190B photography makes it the most useful of Skylab EREP products, although it does not have the multispectral capabilities of S190A or S192 imagery. Approximately 60% of our test site was photographed with the 190B camera; the largest expanse of territory not photographed is in southwestern Utah - eastern Nevada. Frames supplied by NASA in 5- and 9-inch film positives number 34. To date, all 5-inch films and a small number of 9-inch films have been processed into our storage system and analyzed.

The resolution of 5-inch 190B is excellent. Linear features as narrow as 12 feet can be delineated in situations of high contrast, such as dirt roads cutting alluvial fans in a desert environment. The black and white films (e.g., magazine 85) appear to have the best optical resolution, but it is easier to identify small features in the Ektachrome films. Color infrared films have the poorest resolution of 190B film types but resolution is still very good; we have identified features in an urban environment approximately 50 feet square (magazine 87).

A principal advantage of 190B high resolution is that it permits identification of man-made features such as roads and stock tanks that aid in the registration of projected films directly onto published topographic or geologic maps. Thus, items of geologic interest -- color anomalies or linears -- can be accurately located on the map, which makes field reconnaissance less time-consuming and more apt to be successful.

To this point we have been analyzing 190B in 5-inch format (scale 1:950,000) only, on light tables with monoscopic viewing devices. Although our I<sup>2</sup>S multispectral viewer is designed to accept film chips no larger than 70mm, we are attempting to utilize the enlargement capabilities of the viewer on the 5-inch films. The technique we devised is simple: tape the 5-inch film to the underside of the platen, such that the area of interest appears in the opening where a 70mm chip is normally mounted. In this way, the 5-inch film is enlarged to approximately 1:142,000 using the 6.67X front projection facility, and to as large as 1:47,500 using the rear projection facility. S190B films supplied at 2X enlargements will project correspondingly larger.

S190B films are generally excellent in quality; very few processing flaws have been noted in frames analyzed. Parts of some magazines (e.g., 94) are overexposed -- color contrast is minimal. Because overexposure is more apparent in 2X 190B films, we

suspect the problem is in processing, and the original was not overexposed. We are attempting to bring out colors on certain frames by enhancing internegs made from NASA transparencies.

S190B photography complements S190A very well, as anomalous features noted in 190A composited multispectral products can usually be located on 190B films and analyzed as to geologic significance using the better resolution films.

From a geologic standpoint, 190B resolution makes it possible to discern faults, fractures, and other linear features not visible in 190A, ERTS, Apollo, or Gemini imagery. Low sun angles seem to be especially useful in 190B frames to enhance linear features, particularly short-length faults that cut Holocene deposits of uniform color. Lithologic contacts can frequently be resolved and accurately mapped using Ektachrome films.

#### S192 Multispectral Scanner Imagery:

S192 screening films were viewed on light tables, and data fragments over previously-determined sites of interest were requested from NASA in a 70mm, line-straightened format. Approximately 83 seconds of data from seven different EREP passes were ordered. To date, no processed data has been received.

#### S191 Infrared Spectrometer; S193 Microwave Radiometer, Scatterometer, and Altimeter; S194 L-Band Radiometer:

No work of any significance has been performed on any of these experiments. Some S194 data was plotted for orbit 68 over the Sierra Nevada and the Mojave Desert as antenna temperature versus position of spacecraft. No definite conclusions have been formulated as to significance of results.

It is anticipated that research into the usefulness of S191 data will result in the conclusion that resolution is insufficient for geologic investigations.

#### ERTS Imagery:

Over 300 frames from many different ERTS cycles over the test area have been received to complement the Skylab data. Nine-inch prints, positive transparencies, and 70mm negative and positive films were delivered to BESTEC and filed. All of the area was imaged at least once by ERTS sensors under optimum conditions, yielding high-contrast, cloud-free imagery.

Prints are generally poor-quality reproductions, useful only for quick scanning for indexing and coverage purposes. Nine-inch

transparencies are good quality and useful at the scale of 1:1,000,000. The 70mm negatives are of little use, and we find it necessary to enhance 70mm positives photographically to increase contrast for use in the multispectral viewer.

The common map scales (1:1,000,000) at which ERTS 9-inch products are reproduced is a particular advantage of ERTS. In addition, the I<sup>2</sup>S multispectral viewer was designed to enlarge ERTS 70mm chips to 1:500,000, a convenient scale, as many geological and geophysical maps of the same resolution are published at that scale; e.g., the geology, Bouguer gravity, and residual aero-magnetic map series of Arizona. The 1:500,000 scale is especially valuable as 2X enlargements of S190B photography are also at 1:500,000, which will allow a ready comparison of the products as well as evaluation of features noted in ERTS at the higher resolution of 190B.

The synoptic view afforded by ERTS imagery remains a principal advantage, especially regarding identification of lineaments. Compositing four ERTS spectral bands in a multispectral viewer is another advantage. The repetitive coverage of ERTS, which allows temporal evaluations of features of interest, is a third distinct advantage over Skylab photography.

#### Enhancement of Imagery:

Several forms of enhancing imagery are being tried with the intent of producing enhanced prints or films at the best cost-effective rate. Computer processing was not attempted as we wanted a procedure that could be done routinely at low cost by non-technical personnel.

A very simple procedure for enhancing black and white Skylab or ERTS 70mm positives has been established using Kodak duplicating films. The positives are placed in contact with the duplicating films in a vacuum frame which minimizes the occurrences of Newton's rings. The films are duplicated at several different exposure times which serves to enhance different parts of the image. The process is performed by a local printing company. The process is also effective for producing enhanced negatives from which high-quality prints are made.

Another inexpensive method of enhancing prints requires only a standard office copying machine. The procedure is simply to reproduce the print, varying the tone control for lighter or darker copies. We have found that certain features or anomalies not readily apparent in the original print can be accentuated. This method is especially useful for preliminary phases of analysis and emphasizing features to persons not familiar with image interpretation.

A third enhancement method in use involves photographing an image as it is projected onto the front screen of the I<sup>2</sup>S multispectral viewer. The 35mm camera is mounted above the screen, and several pictures are taken of the image at different exposure times. The resulting slides are then analyzed using a conventional 35mm slide projector or the I<sup>2</sup>S viewer. Slides taken in this manner are good records of false color composites made in the multispectral viewer and are also excellent for use in lecture presentations. The slides do not have the resolution of the original that was photographed, but this frequently has proved to be an advantage.

### III. DISCUSSION OF ACTIVITIES

#### Geothermal Exploration:

Geothermal reservoirs are manifested at ground surface by several different geological signatures that can be detected using Skylab imagery. Arcuate anomalies may represent buried intrusive granitic stocks that create hydrothermal solutions or collapsed and buried calderas. Color anomalies and subtle tone variations may indicate rock products altered by thermal waters. Volcanic terranes, of the diverse types associated with many KGAs, may be detected and mapped using Skylab photography. Structural features -- faults and fractures -- that control movements of hydrothermal fluids can be discerned and mapped very accurately using 190B photography.

Two geothermal areas were examined to ascertain which geologic signatures pertinent to exploration for geothermal activity would be most important when using Skylab photography as an exploration tool.

Analyses of S190A and B photography over the Colorado River south of Lake Mead has revealed dikes and faults in close proximity to the host springs at Willow Beach, Arizona. Several large arcuate features noted in the imagery were determined to quite likely be expressions of the extrusive Tertiary volcanic activity in the area, although there is a possibility the arcuates are related to Mesozoic granitic bodies that are common east of the river.

An anomalous light-colored zone east of the beach is interpreted to be Precambrian gneiss altered by thermal fluids possibly associated with the nearby hot springs. A series of north-trending faults observable on both sides of the river may control the extent of the geothermal activity. If so, high temperature waters may be found at shallow depths at sites other than the springs at Willow Beach. The location of faults and the light-colored anomaly has been pinpointed using high-resolution 190B

films. The coloration anomaly is most easily identified in S190A color infrared films. Field reconnaissance of the area is planned for April.

The structural environment of the Coso (California) KGRA has been analyzed using ERTS imagery preparatory to receiving specially-requested Skylab photography of the area. The KGRA is underlain by Mesozoic granitic rocks with Cenozoic basalts and rhyolites outcropping in flows and domes.

Many arcuates of varying dimensions that can be mapped from ERTS imagery may represent surface expressions of the granitic batholith such as fractures, faults, collapse features, or alteration zones. Smaller arcuates evident are probably stocks from the batholith and may be directly responsible for the numerous hot springs and other manifestations of geothermal activity in the area. Known activity apparently is bounded on the south by the Wilson Canyon fault, a left-lateral fault extending from Searles Lake across the Argus Range, Indian Wells Valley, and into the Sierra Nevada. The Airport Lake playa is aligned along the fault. Many northerly-striking faults that can be observed in the imagery appear to terminate against the Wilson Canyon fault. Volcanic domes and hot springs within the Coso area are aligned along the northerly-striking faults.

Coloration anomalies detected in ERTS false-color composites are interpreted to be hydrothermally altered granites.

Arcuate features extend over a larger area than that which currently exhibits geothermal activity. Thus, potential geothermal reservoirs may exist outside of the present KGRA. Detailed analysis of Coso will be delayed until Skylab films are received.

#### Water Resources Exploration:

Investigative efforts have centered on identifying alluvium-filled grabens or structural depressions bounded by faults that might limit horizontal migration of water, thus creating a closed basin. Recharge water would be confined in the subsurface to the basin and a reservoir would be created.

One graben previously mentioned is the Greenwater Valley, Death Valley region, where the valley is bounded on two sides by vertical faults, on the third side by the dip slope of the Black Mountains, and on the fourth by a basement ridge. Gravity maps indicate a substantial thickness of low-density material has accumulated in the valley. Run-off from the Black Mountains and the Greenwater Range into the valley may be effectively sealed from vertical or horizontal movement, creating a water resource.

Mineral Exploration:

For two cases, analyses of Skylab photography have resulted in the identification of anomalies proved by field reconnaissance to be associated with occurrences of mineral deposits. Both the Hunter Mountain and the Black Mountain-Greenwater anomalies were studied extensively with Skylab data in conjunction with published maps and reports previous to field work.

Many other anomalies -- arcuate, coloration, linear -- have been observed in Skylab photos, mapped, and correlated with mining districts but have not yet been field checked.

Petroleum Exploration:

In the extreme southwestern part of the 70,000 square mile test area are the oil and gas fields of the eastern San Joaquin Valley where oil (with associated wet gas) and dry gas are obtained from reservoir rocks which range in age from Eocene to Pleistocene. Sandstones and conglomerates are the principal reservoir rocks, but production has been obtained from fractured shales and from fractured and weathered schist.

The accumulations of oil and gas are contained in structural and stratigraphic traps. The structural traps are anticlines and faults which are superimposed on a regional syncline whose axis lies to the west, outside of the test area. These structural features are strongly aligned in a northwesterly direction parallel to the axis of the basin. The structural trends are reflected by topographic features. Many of the fields in the test area are the result of oil having been trapped against normal faults.

Preliminary examination of 190A films of the eastern San Joaquin reveal that linear trends interpreted to be faults and anticlinal axes can be detected and located. The potential contributions of 190A to petroleum exploration in the area are great, if the linears can be confirmed to be oil field-bounding faults by studying them in high resolution 190B or U-2 photography.

Detailed analysis of the San Joaquin fields will be delayed until additional Skylab data is received. The data will be examined for linears and for the so-called "hazy anomalies" suspected to be related to hydrocarbon accumulations.

IV. ADHERENCE TO SCHEDULE

In general, we are adhering to the schedule detailed in the Milestone Chart (BESTEC Report 101-S-1/75) and no significant

changes to that chart are to be reported at this time.

However, two items that are necessary for the successful completion of our investigation have not yet been received: Argus Exploration Company's field notes and S192 imagery. If this data is not received in the near future our own investigations may be delayed.

#### V. WORK PLANNED FOR NEXT REPORTING PERIOD

Several additional sites in the Death Valley area are to be examined in detail using Skylab data as well as U-2 photography. Another field reconnaissance to Death Valley is planned for April to re-evaluate geological interpretations made from imagery studies.

In order that more sites in the test area can be analyzed in detail, a part-time geologist will be hired to supplement existing staff.

#### VI. PERSONNEL

The following scientific and back-up personnel are presently assigned to the EREP investigation.

Ira C. Bechtold, Principal Investigator  
C. Gregory Wagner, Field Geologist  
John T. Reynolds, Assistant Geologist  
Martha N. Wadsworth, Secretary  
Paul C. Linam, Accountant  
Maurene B. Gray, Clerical Assistant

#### VII. REFERENCES CITED

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VIII. ACKNOWLEDGMENTS

The original contributions of C. Gregory Wagner and John T. Reynolds to methods of imagery enhancement, analysis, and interpretation are gratefully acknowledged. Their contributions to field work are also to be recognized. Martha N. Wadsworth reviewed, edited, and typed this report.

Ira C. Bechtold

Ira C. Bechtold, President  
EREP PI 541